AUTO-THRESHOLD PEAK DETECTION IN PHYSIOLOGICAL SIGNALS

M. L. Jacobson[1]
[1]College of Engineering, United Arab Emirates University, Al-Ain, United Arab Emirates
Member, IEEE, EMBS

Abstract- **In processing physiological signals, it is often necessary to detect periodic, local maxima. There are a variety of peak detection algorithms, but most require a threshold value in order to distinguish peaks from the rest of the data. This brief paper presents implementation of a peak detection algorithm using Matlab© and introduces an innovative method for estimating the threshold value.**
***Keywords* - Peak detection, electrocardiogram, Matlab**

I. INTRODUCTION

In recent years, the variability of the heart rate has been put forth as an indicator to the susceptibility to cardiac disease and early detection neuropathy due to diabetes [1]. Due to the relative ease in data acquisition and the non-invasive requirements upon the patient, the electrocardiogram is often the preferred method for estimating the beat-to-beat, heart rate. As clinical research continues, robust, automated algorithms are required to process the electrocardiogram, detect the QRS complexes and estimate the heart rate.

II. METHODOLOGY

It has been shown that for a normal cardiac system, the heart rate varies due to respiration, maximum inhalation, and cardiac load. Age, cardiac disease, and neuropathy due to diabetes have been shown to impede changes in the heart rate [2]. Therefore, is hypothesized that the heart rate variability may be used as a clinical, low-cost, method to assess a patient's cardiac system.

Recent years have seen the global availability of personal computers and data acquisition systems that adequately sample, collect, and process physiological signals. Programs, such as Matlab [3], interface easily to data acquisition systems and efficiently implement processing algorithms.

As for the electrocardiogram signal, the Lead II position is suggested for providing the maximum R-wave deflection [4]. Therefore, to collect the heart rate data, only a three-lead (right arm, left arm and left leg) electrocardiogram is required. Since the electrocardiogram signal is in the 0 to 10mV range and very susceptible to power-line interference, a 1000x, battery powered, pre-amplifier is implemented before sampling and digitizing the signal using a personal computer based, data acquisition system.

Once collected, detection of the QRS complexes is necessary for determining the beat-to-beat heart rate. Besides power-line interference, the electrocardiogram signal is susceptible to baseline wander and myoelectric interference. Detection of the R-wave maximum slope using a secant, eq. 1, to estimate the derivative [5], which not only avoids the mentioned concerns, but also highlights the location of the QRS complex, as shown in fig. 3.

$$y_i = 2x_{i+2} + x_{i+1} - x_{i-1} - 2x_{i-2} \tag{1}$$

Peaks are defined as local maxima. Specifically, a peak is a maximum value between two consecutive local minima. Similarly, a trough is a minimum value between two consecutive local maxima. To be considered a peak, a sample value must be at least δ greater than a trough. This threshold value, δ, is also used to define a trough as the minimum value less than δ between two consecutive local maxima, per eq. 2.

$$\begin{aligned} x_{P_j} &\equiv x_{T_i} + \delta \le x_{P_j} \bigcap x_{T_{i+1}} + \delta \le x_{P_j} \\ x_{T_i} &\equiv x_{P_j} - \delta \ge x_{T_i} \bigcap x_{P_{j+1}} - \delta \ge x_{T_i} \end{aligned} \tag{2}$$

The Matlab, m-file algorithm of fig. 1 implements the above peak and trough definition [6]. As previously mentioned, the operation of the algorithm depends upon the value chosen for the threshold. Visual inspection of the data allows for easy threshold selection. However, this requires supplemental training of clinical staff acquiring the data and additional time with the patient. Automated threshold estimation greatly improves the heart rate algorithm and simplifies the clinical procedure.

Considering the apriori information, it is known that the peak is positive since the slope of the leading edge is being detected. Therefore, the derivative of the samples greater than zero can be considered as two clusters: one consisting of the peak slopes and the other consisting of the remaining samples.

In order to separate the slope data into two clusters, unsupervised learning, nearest neighbor criteria clustering is suggested. Unsupervised learning may be used since it is known that two clusters are desired. The nearest neighbor criteria is chosen since it requires far less calculation than sum-of-squared-error or Bayesian maximum likelihood criteria [7].

The nearest neighbor criteria is implemented as the absolute difference between a sample and cluster means. The sample is assigned to the cluster mean with smallest difference. Once all the samples have been assigned, new cluster means are determined and samples are again classified to the nearest cluster mean. Algorithm termination occurs when the change in the cluster means is less than ε. Fig. 2 displays the Matlab m-file implementation of the unsupervised learning, two cluster, classifier.

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Once the cluster means are determined, the larger cluster mean is the center of the peak data and used as the threshold for the peak detection algorithm.

```
function [P,T] = PTDetect(x, E)
P = []; T = []; a = 1; b = 1; i = 0; d = 0;
xL = length(x);
while (i ~= xL)
  i = i + 1;
  if (d == 0)
    if (x(a) >= (x(i) + E))
      d = 2;
    elseif (x(i) >= (x(b) + E))
      d = 1;
    end;
    if (x(a) <= x(i))
      a = i;
    elseif (x(i) <= x(b))
      b = i;
    end;
  elseif (d==1)
    if (x(a) <= x(i))
      a = i;
    elseif (x(a) >= (x(i) + E))
      P = [P a]; b = i; d = 2;
    end;
  elseif (d==2)
    if (x(i) <= x(b))
      b = i;
    elseif (x(i) >= (x(b) + E))
      T = [T b]; a = i; d = 1;
    end;
  end;
end;
```

Fig. 1. Matlab m-file algorithm to detect peaks, P, and troughs, T, given a threshold value, E.

```
function [c1, c2]=twoclass(x, e)
c1=x(1); lastc1=c1;
c2=x(2); lastc2=c2;
while 1
  class1=[];
  class2=[];
  for i=1:length(x)
    if (abs(c1-x(i)) < abs(c2-x(i)))
       class1= [class1 x(i)];
    else
       class2 = [class2 x(i)];
    end;
  end;
  c2=mean(class2);
  c1=mean(class1);
  if (abs(lastc2-c2) < e) & (abs(lastc1-c1) < e)
    return;
  end;
  lastc2 = c2;
  lastc1 = c1;
end
```

Fig. 2. Matlab m-file algorithm to perform, unsupervised learning, two class separation, given data, x, and termination condition, e.

III. RESULTS

Fig. 3 displays the results of the peak detection algorithm with auto-threshold setting. Specifically, the secant estimated derivative of 12 consecutive QRS complexes is displayed with the threshold marked as a straight line and the peaks marked with circles.

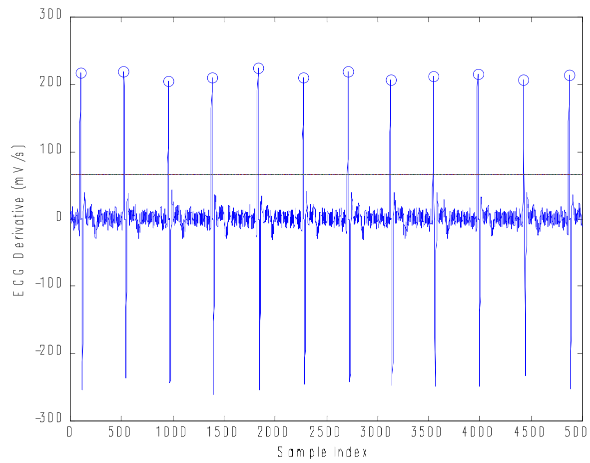

Fig. 3. Sample ECG derivative with auto-threshold and peak detection.

Besides the electrocardiogram, the algorithm has been used successfully to determine respiration, heart rate from blood pressure, and the blood pressure systolic and diastolic pressures.

Even so, it was noted that the auto-threshold algorithm is sensitive to outliers in the data. Therefore, for improved threshold estimation, outlier removal and filtering is suggested.

REFERENCES

[1] H. Adelmann, "Design of a PC-Based System for Time-Domain and Spectral Analysis of Heart Rate Variability," *Computer and Biomedical Research*, v32, pp77-92, 1999.

[2] Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, "Heart Rate Variability, Standards of Measurement, Physiological Interpretations, and Clinical Use," *European Heart Journal*, v17, 354, 1996.

[3] MathWorks Inc., Cochituate Place, 24 Prime Park Way, Natick, MA 01760, USA, (508) 653-1415, http://www.mathworks.com.

[4] M. Akay, "Biomedical Signal Processing," Academic Press, 1994.

[5] G. Friesen, T. Jannett, M. Jadallah S. Yates, S. Quint, H. Nagle, "A Comparison of the Noise Sensitivity of Nine QRS Detection Algorithms," *IEEE Transactions on Biomedical Engineering*, v37, No. 1, 85, January 1990.

[6] B. Todd, D. Andrews, "The Identification of Peaks in Physiological Signals," *Computers and Biomedical Research*, v32, 322, 1999.

[7] R. Duda, P. Hart, "Pattern Classification and Scene Analysis," John Wiley & Sons, New York, pp203-237, 1973.